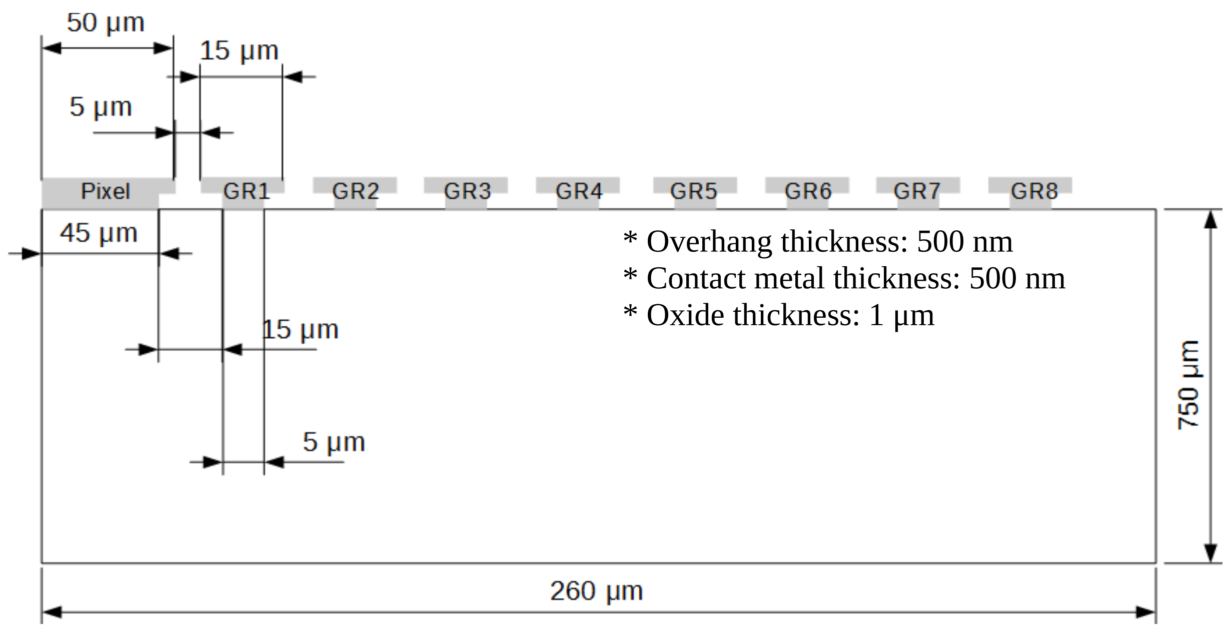
Report on Guard Ring Breakdown on an Arbitrary 8 GR Structure

Simulation Model



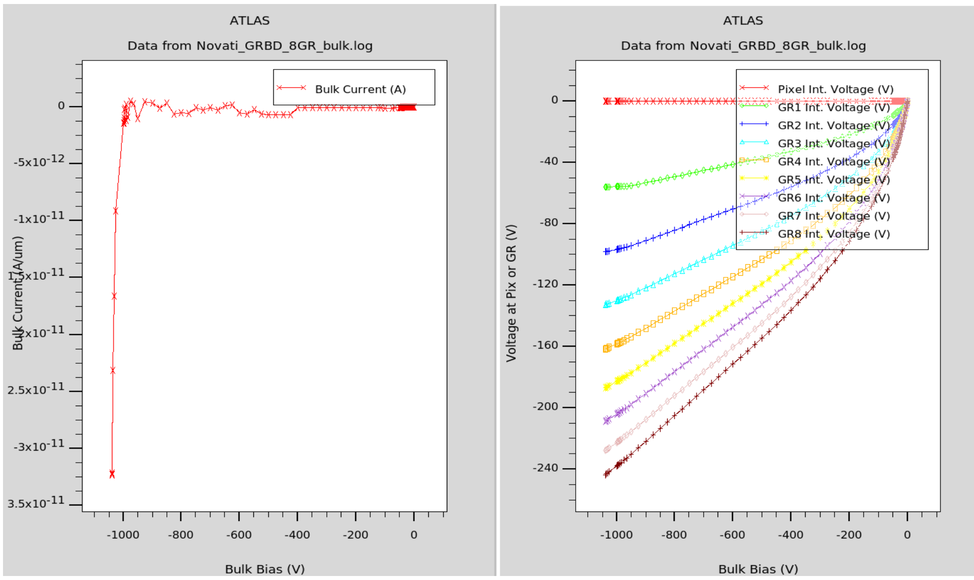
- 8 Guard Ring structure with 50 µm pixel (actually, half-pixel) pitch.
- Gap between contacts: 15 µm
- Overhang: 5 µm per each side
- Doping profile: Curve fitted from Novati SIMS data
- P-stops (width of 5 µm) were implemented between GR and Pixel contacts.

Simulation Setting

- Open circuit was implemented as a lumped resistance of 10^{20} Ω
- Substrate impurity: 10^{12} cm^3 of Boron
- Physical models(provided by Atlas): srh, fldmob, auger, bgn
- SRH constants:
  - Minority electron lifetime(taun0): 1 ms
  - Minority hole lifetime(taup0): 1 ms
- Impact ionization model: Shelburherr
- The simulation was failed to converge right before breakdown (V_{bulk} = -1038 V.)

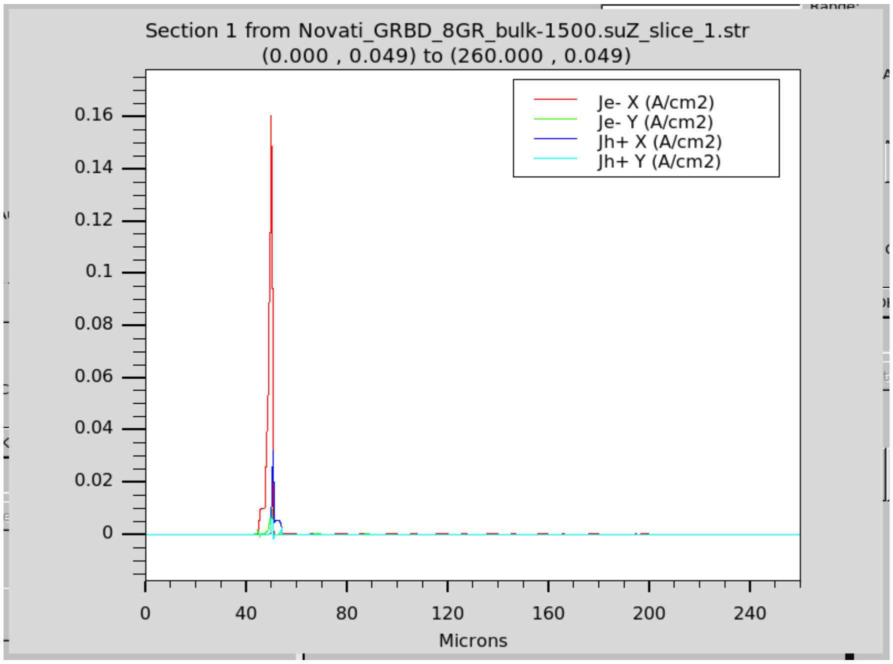
Results

Bulk Current Leakage and GR Internal Bias



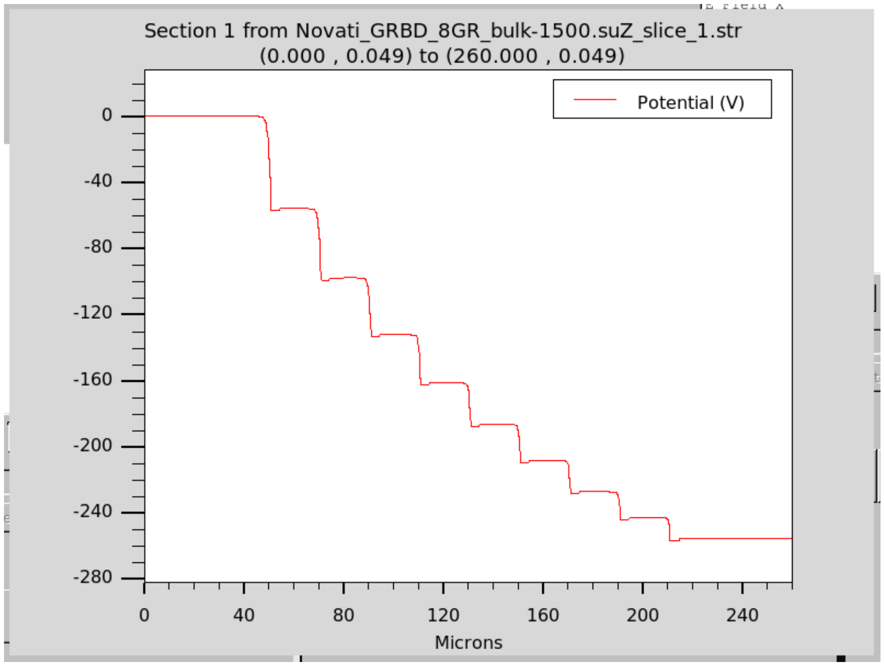
- Simulation was failed to converge at V_{bulk} = -1038 V.
- Outermost guard ring potential stays at -250 V
- Potential difference between pixel and the innermost guard ring (GR1) stays at -70 V.

Current density (2D slice across the model)



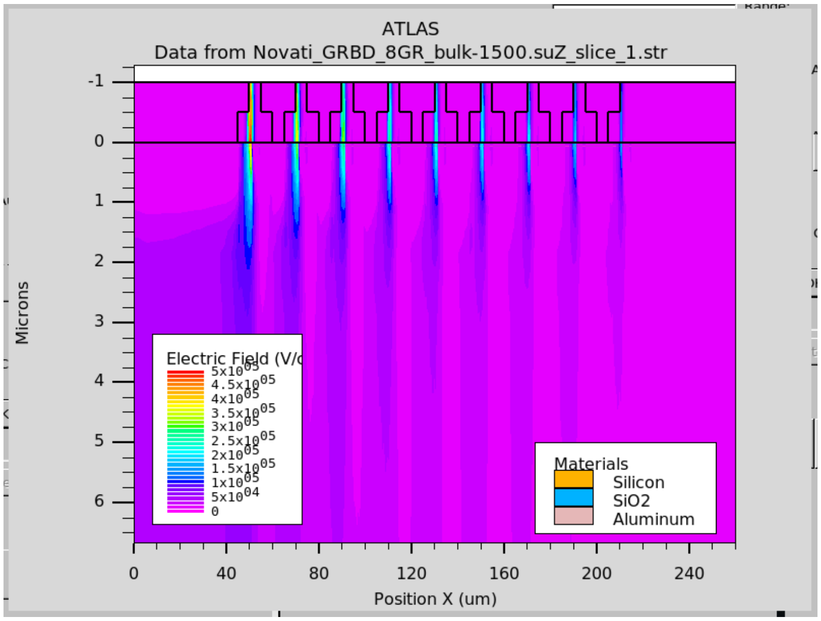
- Current density spikes right between the pixel and GR1 which may have relation with the potential drop.
- Electron current dominates the current as we suspected: Each guard ring pair becomes an enhanced mode(?) n-type MOSFET.
- In fact, the leakage current between contacts exist in other guard ring pairs but they are not as significant as the bulk electrode (anode at the back side of the wafer) leakage current.

Potential (2D Slice across the model)



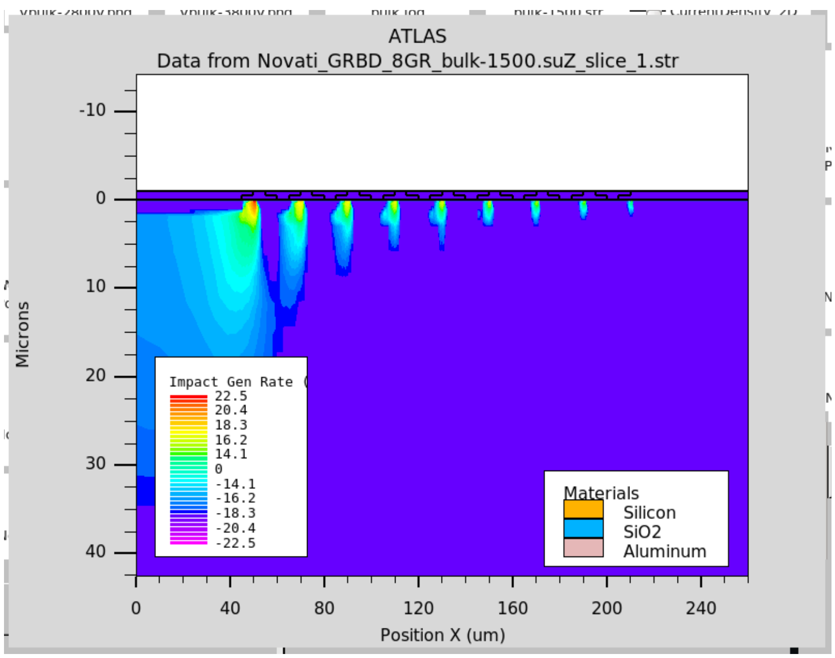
- The potential difference between guard rings decrease as we move further from pixel. Thus, we can clearly see the breakdown actually happens at the first guard ring.
- Which means that the effectiveness of guard ring (potential drop) decreases over the distance: we may consider increasing the implant width of guard rings by the distance from pixel or current collection ring.
- On the other hand, the minimum width of GR implant and metal electrode gap are currently limited by design rule: we may discuss about how to lower the potential drop at this point.

Electric Field 2D Contour Plot



- Indeed, the electric field between Pixel and the first guard ring is the most severe and even extends under the pixel.

Impact Generation 2D Contour Plot



- The impact generation: main source of guard ring to guard ring leakage current seems to be the reverse bias breakdown at p-stop.
- Thus, we may consider removing p-stops altogether or at least lower p-stop doping concentration.

Remarks

1. As we suspected, the breakdown happens at lateral dimension, not through the thick wafer.
2. The potential difference between guard rings must be kept lower than a certain point → May be to be figured out by iterative numerical analysis method?
3. P-stops between guard rings are actually causing the mayhem. Thus, we may consider removing them altogether or lower their implant doping concentration.
4. It seems 5 μm of overhang (towards pixel) does not provide any profit. However, the oxide thickness underneath the overhang was 500 nm in this simulation model.
5. In this simulation, the breakdown happened in fairly high reverse bias (V_{bulk} = -1038 V.) We need to introduce more non-ideal factors, such as high interface trap density, trap states in the silicon bulk, and contact resistance, etc., to match the measured breakdown bias.